Household Energy Expenditure and Income Groups: Evidence from Great Britain

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1. Introduction

The residential demand for energy has been growing steadily in tact with the societies' increasing economic affluence. As a result, the household sector accounts for a significant share of total energy use and economic welfare in modern economies. The residential energy demand is expected to continue to grow in the foreseeable future. This has, in recent years, attracted much attention mainly in relation to the debate on the effect of energy use on climate change.

Household energy use satisfies a multitude of welfare-enhancing services that satisfy a varied range of needs that span from necessities and basics to recreational and luxury consumption. Hence the spending levels on energy have also important socio-economic dimensions of households that need to be better understood. In addition, the determinants and drivers of demand for energy are a varied set of socio-economic factors ranging from income, through housing characteristics and family size to price responsiveness. In particular two important questions arise in this context: what are the main determinants of household energy spending and do the effects of these determinants vary across different income groups?

A small number of studies such as Baker et al. (1989), Yamasaki and Tominaga (1997), Liao and Chang (2002), Wu et al. (2004), Rehdanz (2007), Baker and Blundell (1991), Druckman and Jackson (2008), and Meier and Rehdanz (2008) have analysed aspects of household energy demand and spending. However, there is a need for further studies of this increasingly important consumer segment that focus on socio-economic aspects of household income-groups and energy spending.

Energy spending tends to increase with income but less than proportionally (OECD, 2008) – i.e. overall, energy services may be regarded as a necessity good implying an income elasticity that is greater than zero and smaller than unity.

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However, the link between energy spending and income cannot be explained by simply describing energy as a necessity. Energy spending increases with income, but at an uneven rate. Engel curves for energy expenditures are neither linear nor do they continuously increase or decrease. Rather, they resemble S-curves along which households spending on energy increases or stagnates (or even declines) with income.

Policies targeting residential energy use, climate change, energy efficiency of homes, energy affordability, and fuel poverty need to take income and other important differences among the households into consideration. Moreover, achieving the renewable energy and climate change policy targets can result in significant increases in household energy prices. Hence it is particularly important to examine consumer response to changes in energy prices and income as well as household characteristics such as age, employment status, type of housing, and number of children or retired persons in the household.

The UK household energy consumption increased by 12% between 1990 and 2006 due to an increase in number of households and a trend towards smaller households. Currently, the domestic sector accounts for about 30% of UK's total energy consumption (Utley and Shorrock, 2008). While the energy efficiency of the domestic building stock has improved considerably, the potential for further improvement remains high (DEFRA, 2009; Utley and Shorrock, 2008). The current UK energy policy places particular emphasis on climate change and security of supply concerns both of which emphasise the importance of improving energy efficiency. The 2007 Energy White Paper emphasises the challenges of climate change with energy saving measures as being a major focus areas (BERR, 2008; DTI, 2007) also reiterated in the 2008 Energy Bill.[2]

This paper presents a comparative analysis of determinants of energy expenditure across different income groups. We investigate the relationship between household energy spending and income and several related socio-economic factors. We address this question in the context of Great Britain where extensive household survey data allows a rigorous and robust examination of the questions. We describe Engel expenditure curves for energy spending and differences among income groups in the form of S-curves. We then conduct an econometric analysis of energy spending and estimate income and price elasticities of energy spending for the whole sample and different income levels. We control for the effect of factors such as building types, household characteristics as well as differences between rural and urban areas. In our analysis, we distinguish between overall energy spending, gas, and electricity.

The aim and approach of this paper differs in few respects from previous studies that, for example, use household production frameworks (Baker et al., 1989) or a discrete continuous approach (Baker and Blundell, 1991). We use a real panel data that allows us to use fixed effects models to analyse the dynamics at the individual level while other studies have used pooled cross section data (Baker

[2] As the focus of this study is on household energy spending and the differences between income groups, some of our analysis is relevant for the important issue of fuel poverty. In Great Britain, households that spend over 10% of their income on energy are regarded as fuel poor. In 2007, an estimated 4 million households or 16% of the total were fuel poor (DEFRA and BERR, 2008; DECC, 2009). The main reasons for fuel poverty are energy prices, low energy efficiency of homes, and the level of income. In particular, fuel poverty among the households with children, elderly, disabled or persons with long-term diseases is estimated at approximately 80% (DEFRA and BERR, 2008).

and Blundell, 1991; Baker et al., 1989; and Rehdanz, 2007). Moreover, the data used in this study covers the post-liberalisation period of the electricity and gas sectors in the UK. Also, we are mainly interested in the relationship between income and energy spending among different household groups. While previous studies examine two or three income groups (Baker et al. 1989 and Nesbakken, 1999), we explore and compare the link between income and energy spending in detail for five income groups. We show that although energy spending changes with income level, the direction of the change is not unambiguous. We also estimate income elasticities for energy spending among different income groups rather than for energy spending shares[3] (Baker et al., 1989).

The next section gives a brief discussion of household energy demand and review of the relevant literature. Section 3 describes the methodology used in the paper. Section 4 describes the data used and then gives the results of the graphical analysis. Section 5 presents and discusses the results of our empirical analysis for different income groups and different fuel types from regression results. Finally, Section 6 presents the main conclusions.

2. Previous Studies

In a study on the potential of budget standards, Bradshaw et al. (1987) present the 'S-curve analysis' as a statistical technique to identify expenditure levels that serve as such standards. They discuss the S-curve approach as a mean to detect inflection points where the expenditure allocated to a necessity good such as energy, food, and clothing turns over. In other words, as income increases, spending on the necessity good increases (less than proportional) until an inflection point is reached beyond which spending flattens (or even declines) before it continues to increase again. For the purpose of our study, the inflection points of energy spending S-curves from large samples can shed some light on the changing nature of energy use as a necessity, normal, or other type of good (or service) as a function of household income. In the next section we revisit the energy spending S-curves for the UK households in greater detail.

Residential energy use has been the subject of some early studies and econometric analysis prior to the oil price shocks in the 1970s. An early study by Houthakker (1951) examined British urban electricity consumption. A number of studies have since been undertaken. Madlener (1996) presents a detailed survey of the early literature (1951-1996) which mainly includes studies of demand for electricity. The survey points to the difficulties of comparing the findings of many of the studies as they use a range of approaches and techniques.

Baker et al. (1989) develop a two stage budgeting model of fuel consumption and explore households' responses to price changes and responses of different age groups and birth cohorts. The model assumes that, in the first stage, households allocate their income as budget shares between fuel consumption and non-fuel goods. In the second step, households make within-fuel decisions and allocate

[3] An approach using energy spending shares, instead of overall energy spending, addresses different issues. Analysing energy spending shares is mainly an allocation matter. The first question is how much of a household income is devoted to energy and then the second is how the energy spending share is allocated among the different fuels. In energy spending analysis we focus instead focus on the main drivers of energy spending.

their energy spending among different fuels. They control for a range of socio-economic characteristics and use three income groups: lower, middle and top income deciles. The results indicate that both gas and electricity are necessities and for some household electricity is an inferior good. Overall, household responses vary considerably according to household types.

Nesbakken (1999) analyses energy consumption of households in Norway using a discrete choice model. The study explores the choice of heating equipment and models the residential energy consumption as being conditioned on the equipment. Income and energy price variables are analysed for households with incomes below and above the mean income. The results show that short run income elasticities are equal to 1 and hardly depend on income group. In the long run low income households have an elasticity of 0.18 and high income households of 0.22. Households in the high-income group had a higher price elasticity of energy consumption (-0.66) than low-income households (-0.33). While a higher price responsiveness of high income households was not in line with the hypothesis of the study, this is explained by higher energy consumption among high income households. Hence, their marginal utility[4] from energy consumption is comparably low. If they reduce their energy consumption as energy prices increase, the loss of utility is comparably low. In contrast, low income households face larger loss of utility if energy prices increase and thus they do not reduce their energy consumption to the same extent as high income households.

Roberts (2008) focuses on low-income households in Britain and shows that some of these have relatively high levels of energy use and in particular, many elderly people who live in large and thermally inefficient homes. Some studies have focused on the age aspect. In addition to the above mentioned Baker and Blundell (1991) who control for age and birth cohort of the heads in their study of the UK households, Yamasaki and Tominaga (1997) examine the long-run impacts on energy demand due to an ageing population in Japan in order to predict household fuel and light expenses for 2010. The number of Japanese households will rapidly increase and there are increasingly more elderly single-person households who are also likely to use more energy. Liao and Chang (2002) analyse a cross section of US data from 1993 and find that the aged groups spent significantly more on space heating and less on water heating compared to the younger groups and that the difference increases with age differences.

Druckman and Jackson (2008) analyse UK household energy use at national and local level using data from the Expenditure and Food Survey 2004-05. The study uses the Local Area Resource Analysis (LARA) model to estimate household energy use in specific neighbourhoods. Socio-economic and demographic characteristics of households are regarded as important drivers. The findings show a strong link between energy consumption, carbon emissions, and income.

[4] It is assumed that at very high levels of energy consumption the utility of consuming an extra unit of energy still increases but at a decreasing rate. If richer households consume much larger amounts of energy they will have a lower marginal utility of energy spending. For poorer households an extra unit of energy will lead to a much higher increase in energy, i.e. the marginal utility of the extra unit is higher for a poor household than it is for a rich household. Thus, if energy prices increase both types of households might reduce their energy spending but the richer households will reduce energy spending to a much larger extent as their loss of utility will be comparatively lower. If the poor households reduce their energy spending by the same amount they will suffer from a much larger loss of utility.

Waddams Price et al. (2007) examine the fuel poverty and its official definition in the UK. Using survey data of low income households the study examines the relationship between the objective fuel poverty measure and the attitude of households including their belief in the extent to which they can afford sufficient energy. The study shows that the households' perception of being fuel poor is linked to their actual fuel poverty.

Some studies address the tenant-landlord debate. Rehdanz (2007) analyses residential space heating expenditures of German households for 1998 and 2003 using a panel of socio-economic data. The study shows that owners are less affected by price increases than tenants because of higher energy efficiency of owner occupied dwellings. Meier and Rehdanz (2008) analyse heating expenditures per room in UK households between 1991 and 2005 and show that owner-occupied households are more sensitive to price and income changes but this is mainly due to differences in dwelling types.

A study of energy consumption in Denmark by Leth-Petersen and Togeby (2001) uses panel data for the 1984-1995 period. The study focuses on effects of technical characteristics of apartment blocks on the demand for space heating. The estimated price elasticities are relatively small, -0.082 for gas and 0.024 for district heating However, as income is not observed its effect cannot be analysed. Wu et al. (2004) examine the demand for space heating in Armenia, Moldova, and Kyrgyz Republic using household survey data. In these countries real energy prices have continuously increased while real incomes have stabilised. The study focuses on provision of affordable heating for the urban poor. The study shows that price elasticities can be high and in some regions incomes are not sufficient to afford space heating from district heating systems making these systems unviable.

We analyse electricity, gas and overall energy spending for a large sample of households in Great Britain. We discern inflection points and discuss different income levels and links to energy spending. We use a large panel data set and estimate income price elasticities for the whole sample as well as for different income groups. Understanding the role of income is essential for designing target oriented policy measures. Further increases in energy prices could lead to low income households being worse off and richer households still not having strong incentives to reduce their energy consumption. Such an outcome would only lead to a worsening of the situation instead of achieving, for example, a reduction of CO_2 emissions. Hence different policy measures may be needed for different income groups.

3. Energy Expenditure and Income Groups: Stylized facts

Figures 1-6 depict Engel expenditure curves for energy spending[5] for British households and show how energy spending varies with income levels (also capturing the effect of other variables on energy spending that are correlated with income). At the lowest levels, an increase in income first leads to higher energy spending. This can mainly be explained by the necessity-characteristic of energy.

[5] In our analysis energy spending is the sum of spending on gas, electricity and fuel oil. We also analyse electricity and gas spending, separately but do not consider spending on fuel oil any further, thus we do not estimate a fuel oil equation. The number of observations for households using oil is fairly low (3,255 for the whole sample). Oil and gas are both used for heating though in Great Britain gas is the dominant heating fuel. For a more detailed analysis of gas and oil usage see e.g. Meier and Rehdanz (2009).

As shown in the figures, this relationship in the curves generally holds until an inflection points is reached beyond which an increase in income leads to a stagnation/decrease in energy spending. In other words, income elasticity of energy spending declines at inflection points.

At the inflection points the income and associated energy spending seem to reach a level that enables a certain lifestyle and energy usage. Beyond this point, energy becomes less important for households and any additional income can be devoted to other goods. In terms of consumption economics the first inflection point on the Engel curve can be interpreted as the point where the households' income level satisfies their basic energy needs. Beyond this inflection point, additional spending on energy is then increasingly associated with services of normal or luxury character. This insight is with reference to the consumption pattern of a representative sample. The large size of our annual samples and their wide range of income levels provide confidence in representativeness of our observations from the figures.

Figures 1-6 resemble S-shaped Engel curves. At the first inflection point energy spending first decreases but increases again with income. In practical terms, a partial explanation of inflection points is that higher income is associated with larger homes and hence higher energy spending and higher utilization of a larger number of energy using appliances. The inflection points reflect (local) maximum utility from energy use and the associated income level. Energy spending briefly stagnates or even declines before it rises again with income. This may reflect underlying changes in the lifestyles that affect the level and pattern of energy use and spending.

The graphs for selected years between 1991 and 2006 also reflect the changes in the relationship between energy spending and income over time. As shown, the inflection point has moved from about £700 in 1991 to roughly £850 in 2006. The income levels at the inflection points have risen as well. In 1991, the energy spending turned over at an income level of almost £20,000 per year, while in 2006 the turnover point is at £30,000. Given that real income distribution remains fairly stable over time this indicates that an increasing number of households are below the inflection points' income level.

In our sample, the number of households below the inflection point first decreases and then increases again. In 1991, 52% of households (2,554) have energy expenditures below the inflection point; the share declines to 46% in 1994, and then rises again to 51% in 1997, 52% in 2000, 55% in 2003 and 60% in 2006. A more recent short-term development can be seen by comparing the last two graphs: in 2003 the inflection point is reached at an income level of around £26,000 per year and energy spending of around £680. Three years later the income level at the inflection point is £4,000 higher and the energy spending at this level increased by almost £200.

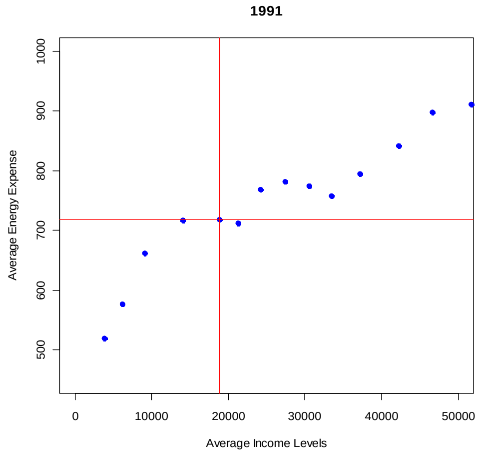

Figure 1 Income and energy spending 1991
No. of observations 4,696

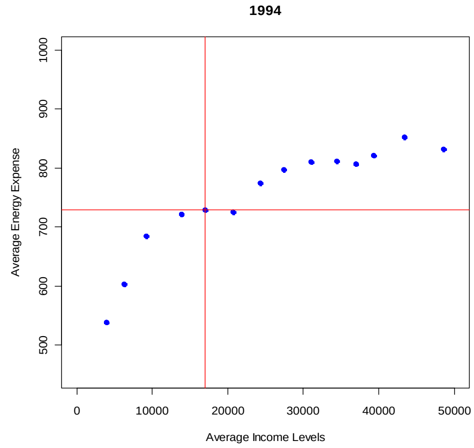

Figure 2 Income and energy spending 1994
No. of observations 4,202

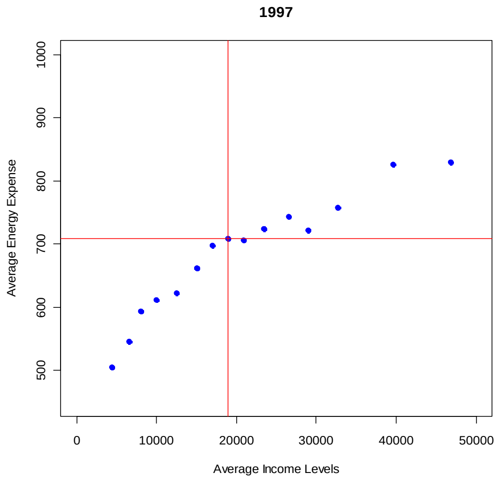

Figure 3 Income and energy spending 1997
No. of observations 4,386

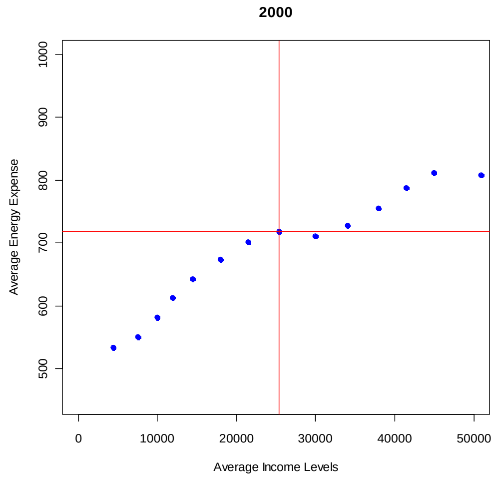

Figure 4 Income and energy spending 2000
No. of observations 7,065

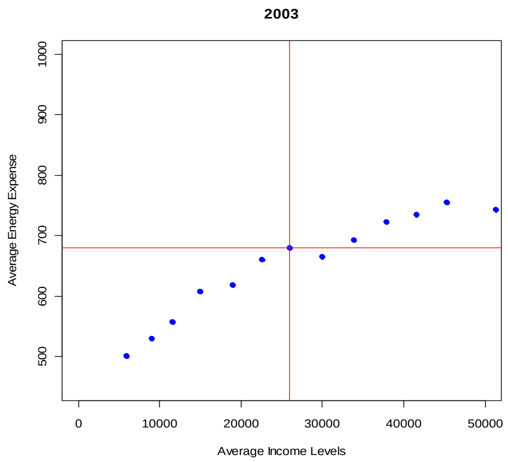

Figure 5 Income and energy spending 2003
No. of observations 6,959

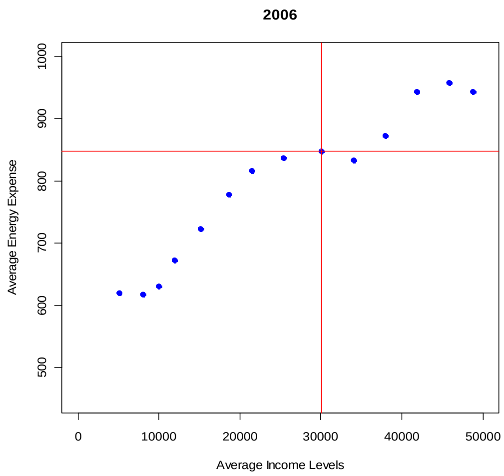

Figure 6 Income and energy spending 2006
No. of observations 6,071

The notion of inflection points is little used in the debate of energy spending (see Bradshaw et al., 1987 for a rare example). What does it mean for a household to be below or above this income threshold? One argument could be that households may need support to reach the inflection point's income level while rich households can be incentivised to reduce some of their energy spending that is beyond basic needs. The inflection point also points distributional implications of energy spending as well as energy policy measures. We suggest policy measures tackling climate change to be designed in to redistribute energy among different income groups.

The above discussed developments especially differences in household energy spending levels among other factors depend to a large extent on energy price movements. Figure 7 show the development of gas and electricity prices for the period of our study. Prices for gas and electricity have developed quite similarly.

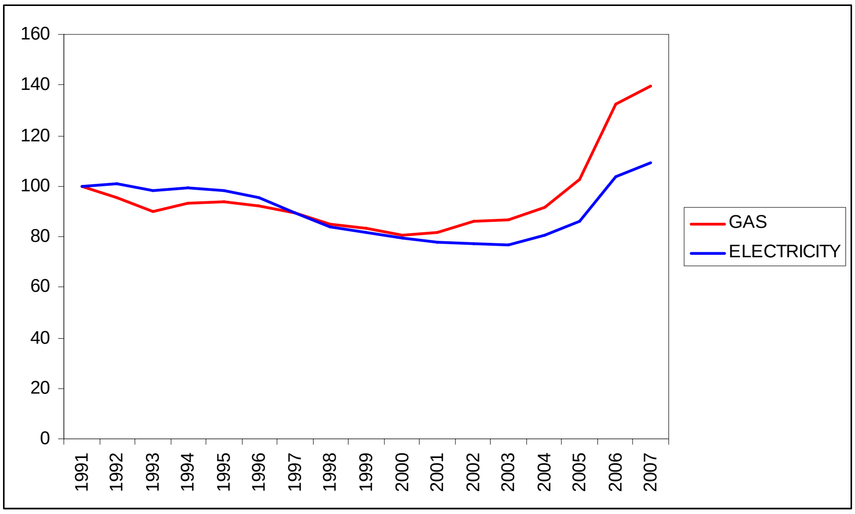

Figure 7: REAL GAS AND ELECTRICITY PRICE INDEX, 1991=100
Source: IEA (2005; 2007) and ONS (2009)

Both prices were below levels of 1991 until 2005 and reached comparably low levels in 2003. Since 2005 both prices have increased significantly in real terms impacting the link between energy spending and income. The figure also shows that electricity prices largely follow the price of gas reflecting the rapid increase in the share of combined cycle gas turbines (CCGT) as the preferred generation technology by new entrants in the post liberalisation period in the UK (Newbery, 2005).

4. Methodology

The scatter plots depicted in Figures 1-6 are a simple representation of household energy spending over time as they only reflect the changes in income energy spending levels. In order to do a more detailed analysis we specify and estimate a set of econometric models of the main socio-economic determinants and drivers of energy spending. Also, as we have a particular interest in the role of income we then split our sample and perform an analysis for different income groups. We first perform the analysis for household electricity spending and then proceed with those of the natural gas and overall energy spending (i.e. electricity, natural gas, and fuel oil).

We base our study on a large and comprehensive survey data that comprises detailed information on various aspects of households in Great Britain over several years. Using panel data allows for a broad micro-econometric analysis as different households can be compared at different points of time while individual households can be observed over time. Also, the size of the dataset allows splitting of the panel into several income groups for comparison in terms of their energy spending.

In general, we expect energy expenditures to increase with higher gas and electricity prices, household income, and the number of children. Normally, energy spending is higher for households living in detached houses and lower for those living in flats.[6] We use dummy variables to distinguish between these types of housing. We also control for households that live in their own properties (OWNED), households that do not have access to gas (NO GAS) and households that live in rural areas (RURAL).[7] We hypothesize that households with no gas expenditures will have higher energy and higher electricity expenditures due to absence of competition from gas. This hypothesis also justifies the implementation of the rural dummy as lack of access to gas is more common in rural areas.

For our purposes, we use a set of fixed effects models. Such models take into account the unobservable and non-measurable effects of all the different individual units. In our case, these effects cover specific household characteristics that do have an influence on their energy spending but we cannot control for them. In general, a fixed effects model can be expressed as in Equation (1).

$$Y_{it} = \beta X_{it}^{'} + v_i + \varepsilon_{it} \tag{1}$$

For each household *i*=1,...,N the fixed effect is given by v_i, this effect is household specific and time-invariant. Accordingly, each household has an individual intercept which is constant over time. A fixed effects approach can address cross-sectional heterogeneity in the dataset and control for unobservable household-specific effects that cannot be captured by control variables. A consequence of using fixed effect models is that it is not possible to control for any time-invariant variables as these are included in the fixed effects. However, inability to control for time invariant variables is not hindering our analysis as the variables that we use in our models are not time invariant.[8] Also, the assumption that fixed effects are constant over time implies that time-varying unobservable household characteristics are captured by the error term ε_{it}. Unobservable household characteristics might cover different attitudes such as environmental awareness

[6] We cannot control for weather conditions, different regions, or single years. In Meier and Rehdanz (2008) the number of heating degree days has positive significant impacts on households heating expenditures although, the size and significance of the coefficient are rather low. Their analysis of regional differences shows that heating expenditures are highest in Scotland and lowest in the south of England. Here, we do not control for different regions but explore differences between urban and rural areas in general. Also, we use a time trend and the square of the time trend but do not control for each year separately. The gas and electricity prices vary over time and we control for these prices.

[7] According to our definition urban areas are urban settlements with a population of 10,000 or more as well as towns and fringes independent from the population in the wider surrounding area. Villages, hamlets, and isolated dwellings are treated as rural areas.

[8] A fixed effects model does not allow the estimation of time invariant variables. Also if variables are rarely variant their impacts may only be inefficiently estimated.

and assuming these characteristics to be time-invariant does not represent a major limitation of our analysis.

Some studies focus on different model approaches using fixed effect models, e.g. Sherron and Allen (2000), Farsi and Filippini (2004) and Hausman and Taylor (1981). The debate on model specification focuses on the fixed versus the random effects approach. Random effect models also capture the effect of individual differences but these effects are treated as random effects instead of fixed effects. The random effects enter the model as stochastic variables. Using this approach implies that specific household characteristics are randomly distributed across households but are assumed to be constant over time. The random effects approach is based on the assumption that the specific individual effects are uncorrelated with the explanatory variables. If this assumption is correct, the random effects approach leads to more efficient estimation results. If the assumption is wrong, the approach leads to biased results.

We can test whether the random effects and the explanatory variables are correlated using the Hausman test of the hypothesis that differences in coefficients are not systematic. The test forms the differences between the coefficients of fixed effects and random effects models and examines if the coefficients vary systematically. If the results of the two models differ, the unobserved heterogeneity is correlated with the explanatory variables and as a result, random effects results are biased while fixed effects results are unbiased (Hausman, 1978; Owusu-Gyapong, 1986; Baltagi et al., 2003; and Hausman and Taylor, 1981). In our analysis we applied the Hausman test and the random effects model was rejected. Hence, we use the fixed effects approach in estimating our models. The results of our Hausman test results are shown in Section 6.

We estimate the effect of the above discussed independent variables on total energy spending as well as on the spending on electricity and natural gas. We distinguish among these fuels as they are mainly used for different purposes. While electricity can be used for all electric appliances, gas is mainly used for heating and hot water supply. Total energy spending covers both effects and also contains spending on oil which is used for heating, too. We begin with separate regressions for electricity and gas spending and then analyse overall energy expenses as specified in Equations (2) to (4).

Electricity:

$$ElecS_{it} = \beta_{Inc} Inc_{it} + \beta_{Pe} Pe_t + \beta_{Pg} Pg_t + \beta_{nG} NoGas_{it} + \beta_t Tr_t + \beta_S SocEc_{it} + \beta_B B_{it} + v_i + \varepsilon_{it} \tag{2}$$

Gas:

$$GasS_{it} = \beta_{Inc} Inc_{it} + \beta_{Pe} Pe_t + \beta_{Pg} Pg_t + \beta_R Rur_{it} + \beta_t Tr_t + \beta_{t2} Tr_t^2 + \beta_S SocEc_{it} + \beta_B B_{it} + v_i + \varepsilon_{it} \tag{3}$$

Energy:

$$EnS_{it} = \beta_{Inc} Inc_{it} + \beta_{Pe} Pe_t + \beta_{Pg} Pg_t + \beta_{nG} NoGas_{it} + \beta_t Tr_t + \beta_{t2} Tr_t^2 + \beta_S SocEc_{it} + \beta_B B_{it} + v_i + \varepsilon_{it} \tag{4}$$

where:

$ElecS_{it}$: Annual household's electricity expenditures.

$GasS_{it}$: Annual household's gas expenditures.

EnS_{it} : Annual household's energy spending (sum of gas, oil[9], electricity).

Inc_{it} : Annual household's income[10].

Pe_t : Average annual electricity price.

Pg_t : Average annual gas price.

$NoGas_{it}$: Indicates whether a household has access to gas or not.

Rur_{it} : Indicates whether a household lives in a rural area or not.

Tr_t : Trend variable (linear 1-17).

Tr_t^2 : Square of trend variable.

$SocEc_{it}$: Socio-economic characteristics (number of children, property ownership).

B_{it} : Building characteristics (detached and semi-detached houses, terraced and end-terraced houses, flats).

v_i : Fixed effect.[11]

We use short-term models of energy expenditures, i.e. we do not consider technological adjustments.[12] We are interested in spending levels related to income and not in appliances used. We assume that appliances are related to income and income levels indirectly capture the differences in appliances, as well. The short-term approach to modelling demand/expenditure has been used in other studies reviewed earlier - e.g. in Meier and Rehdanz (2008); Rehdanz (2007); and Leth-Petersen and Togeby (2001).

We use a log-linear functional form, i.e. we take the logarithm of energy expenditures, energy prices, annual household income and the number of children. Also, we use the Consumer Price Index, CPI of the UK Office for National Statistics (ONS) with 2005=100 (ONS, 2009) in order to adjust all monetary values to overall price developments. The dependent variables are the log of household annual electricity, gas, and energy expenditures in 2005 prices.

We estimate separate regression models first for the whole sample and then for each of the following five income groups with annual household incomes of: (1) ≤£9,000; (2) >£9,000-20,000; (3) >£20,000-30,000; (4) £30,000-45,000; and (5) >£45,000. The income groups have been determined in such a way that they represent different income thresholds. Given that low income is defined as 60% of median income levels[13], low income on average is below £9,000 while the average income is between levels £20,000-30,000. As our aim is to compare adjustment

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9 The dependent variable in this model is the sum of the dependent variables of the gas and electricity spending models plus spending on oil.

10 We control for the log of annual household income. We also controlled for the log of income and income squared for the whole sample which captures the effect of the changing link between energy spending and income. The results of these estimations were, however, not as meaningful for comparison of different income groups and are not discussed in this paper.

11 Using the 'Stata xtreg, fe' command, we assume that average value of the fixed effects of all households is equal to zero.

12 I.e. the FE estimator just takes into account within-household annual (short-term) variations.

13 ONS (2009)

processes of different income groups, we select our income groups to ensure a good representation of certain income thresholds.

5. Data

The data used in this paper is based on the British Household Panel Survey (BHPS). The dataset is an unbalanced panel of more than 5,000 households, over a 17 year period from 1991 to 2007. As part of the survey approximately 10,000 individuals have been re-interviewed annually. The primary objective of the survey is to enhance understanding of social and economic change at individual and household level in Britain. The BHPS covers the major topics of household organization, labour market, income, and wealth as well as housing etc. It should be noted that although the survey is stated to be nationally representative, it is not certain that this is necessarily the case along the dimension of household income. The selection of the survey sample is based on a clustered stratified sample of addresses in Great Britain; and the main selection criteria are age, employment, and retirement.

The survey contains data on annual households spending on different fuels, some information on buildings (building type, ownership of property), and regional location of households. It is also possible to differentiate between households living in urban and rural areas. In addition, the data includes annual household income as well as several household characteristics such as size, age of members, employment status. Tables 1 to 3 present the summary statistics for the data and different models used in this paper. Except for TREND variables and dummies we use the natural logarithm of all explanatory variables in our analysis. In order to capture the effect of price developments we match the BHPS with annual data on average yearly UK energy prices for gas and electricity. The data is drawn from the IEA (1997) and IEA (2008).[14]

Variables	Obs	Mean	Std. Dev.	Min	Max
ELECTRICITY*	77,116	368.70	224.14	1.05	8,592.91
INCOME*	77,116	26,293	21,339	76	764,801
ELECTRICITY PRICE*	77,116	0.08	0.01	0.07	0.10
GAS PRICE*	77,116	243.42	42.83	207.89	359.71
NO GAS	77,116	0.12	0.32	0	1
TREND	77,116	9.95	4.54	1	17
OWNED	77,116	0.73	0.45	0	1
CHILDREN	77,116	0.57	0.96	0	9
DETACHED HOUSE	77,116	0.22	0.42	0	1
SEMI-DETACHED HOUSE	77,116	0.33	0.47	0	1
END-TERRACED HOUSE	77,116	0.08	0.27	0	1
TERRACED HOUSE	77,116	0.20	0.40	0	1
FLAT	77,116	0.17	0.37	0	1

*Electricity spending and INCOME in GBP per year. Monetary values are in real terms 2005 prices. Gas prices are in GBP per 107 kilocalories GCV. Electricity prices are in GBP per kWh.

TABLE 1: Summary statistics of data used (Electricity Spending)

[14] The IEA data is also published by the Department of Energy and Climate Change (DECC).

Variables	Obs	Mean	Std. Dev.	Min	Max
GAS*	71,619	388.15	243.50	0.96	11,171.38
INCOME*	71,619	26,774	21,199	76	560,443
ELECTRICITY PRICE*	71,619	0.08	0.01	0.07	0.10
GAS PRICE*	71,619	245.60	43.84	207.89	359.71
RURAL	71,619	0.07	0.26	0	1
TREND	71,619	9.88	4.71	1	17
TREND SQUARED	71,619	119.92	88.65	1	289
OWNED	71,619	0.74	0.44	0	1
CHILDREN	71,619	0.59	0.97	0	9
DETACHED HOUSE	71,619	0.22	0.41	0	1
SEMI-DETACHED HOUSE	71,619	0.35	0.48	0	1
END-TERRACED HOUSE	71,619	0.08	0.28	0	1
TERRACED HOUSE	71,619	0.21	0.41	0	1
FLAT	71,619	0.14	0.35	0	1

*Gas spending and INCOME in GBP per year. Monetary values are in real terms 2005 prices. Gas prices are in GBP per 10^7 kilocalories GCV. Electricity prices are in GBP per kWh.

TABLE 2: Summary statistics of data used (Gas Spending)

Variables	Obs	Mean	Std. Dev.	Min	Max
ENERGY*	77,116	723.81	377.21	1.07	11,915.57
INCOME*	77,116	26,293	21,339	76	764,801
ELECTRICITY PRICE*	77,116	0.08	0.01	0.07	0.10
GAS PRICE*	77,116	243.42	42.83	207.89	359.71
NO GAS	77,116	0.12	0.32	0	1
TREND	77,116	9.95	4.54	1	17
TREND SQUARED	77,116	119.67	85.78	1	289
OWNED	77,116	0.73	0.45	0	1
CHILDREN	77,116	0.57	0.96	0	9
DETACHED HOUSE	77,116	0.22	0.42	0	1
SEMI-DETACHED HOUSE	77,116	0.33	0.47	0	1
END-TERRACED HOUSE	77,116	0.08	0.27	0	1
TERRACED HOUSE	77,116	0.20	0.40	0	1
FLAT	77,116	0.17	0.37	0	1

*Energy spending and INCOME in GBP per year. Monetary values are in real terms 2005 prices. Gas prices are in GBP per 10^7 kilocalories GCV. Electricity prices are in GBP per kWh.

TABLE 3: Summary statistics of data used (Energy Spending)

6. Results

We first discuss the results for the fixed effects analysis of electricity expenditures for all the nearly 14,000 households in the sample, which includes more than 77,000 observations for the period of study followed by analysis of sub-samples of a set of income groups. Next, we discuss the results for the gas and then total energy spending.

Hausman Test results

Test: Ho: difference in coefficients not systematic		
Electricity spending	chi2(11) =	590.08
	Prob>chi2 =	0, Random effects is rejected.
Gas spending	chi2(12) =	280,94
	Prob>chi2 =	0, Random effects is rejected.
Energy spending	chi2(12) =	594,44
	Prob>chi2 =	0, Random effects is rejected.

TABLE 4: Hausman Test result for electricity, gas and overall energy spending (All households)

The estimation results for electricity spending of households are presented in Table 4. The results for the Hausman test are given in Table 5. The P-value (Prob>chi2) is equal to zero and thus significant. The coefficients estimated by the random effects model are different from those of the fixed effects model and the random effects model is rejected. The estimated income elasticity of electricity spending is 0.06 for the whole sample indicating that electricity is a necessity service (or good).

The results for our sub-samples, however, reveal a rather varied picture across the income groups. The income elasticity is lowest for the lowest income group and increases in tact with income up to incomes between £30,000 and £45,000. A further income increase leads to lower income elasticity. At the lowest income levels, an income increase leads to a small extent to buying additional appliances or more frequent use of the existing ones. With further increases in income, an increasing number and usage of appliances in a household and thus increase in electricity spending to a larger extent. For the highest income levels the change in consumption pattern and lifestyle does no longer have as strong impact and the higher income is spent on other goods.

A similar development can also be observed for price elasticity of spending on electricity. For the whole sample, we estimate an elasticity of 0.098 and find the lowest elasticities for the lowest income groups. It should be noted that as we explore price elasticity of spending, a low estimated value of the coefficient implies a stronger reaction (in terms of demand reduction) in response to price changes. The price elasticity increases with income and thus the price sensitivity decreases in income.

Dep. Variable: Log of ELECTRICITY EXPENDITURES						
VARIABLES	ALL	≤ 9,000	9T-20T	20T - 30T	30T-45T	≥ 45T
INCOME	0.062***	0.046***	0.050***	0.076**	0.152***	0.098***
	(16.25)	(3.17)	(2.74)	(2.22)	(4.13)	(4.91)
ELECTRICITY PRICE	0.983***	0.804***	0.866***	1.183***	1.329***	0.635***
	(14.37)	(4.53)	(6.07)	(7.69)	(7.80)	(3.08)
GAS PRICE	-0.218***	-0.221	-0.151	-0.393***	-0.463***	0.090
	(-3.94)	(-1.56)	(-1.31)	(-3.16)	(-3.34)	(0.53)
NO GAS	0.296***	0.236***	0.319***	0.267***	0.355***	0.207***
	(27.96)	(8.08)	(14.74)	(9.40)	(11.12)	(6.67)
OWNED	0.069***	0.036	0.036*	0.072***	0.064**	0.059
	(6.93)	(0.97)	(1.69)	(2.88)	(2.25)	(1.50)
CHILDREN	0.137***	0.099**	0.151***	0.162***	0.140***	0.106***
	(21.02)	(2.35)	(8.20)	(10.20)	(9.68)	(6.88)
DETACHED HOUSE	0.122***	0.013	0.114***	-0.019	0.099***	0.194***
	(9.95)	(0.32)	(3.93)	(-0.60)	(2.85)	(5.29)
SEMI-DET. HOUSE	0.045***	-0.026	0.080***	-0.060**	0.061*	0.108***
	(4.25)	(-0.89)	(3.51)	(-2.17)	(1.89)	(3.02)
END-TERR. HOUSE	0.036***	0.009	0.044*	-0.038	0.016	0.089**
	(3.02)	(0.28)	(1.77)	(-1.26)	(0.43)	(2.12)
TERRACED HOUSE	0.013	-0.055*	0.044*	-0.072**	-0.007	0.038
	(1.19)	(-1.93)	(1.92)	(-2.57)	(-0.20)	(1.01)
TREND	0.003**	-0.006*	-0.006**	0.006**	0.010***	0.005
	(2.11)	(-1.80)	(-2.41)	(2.26)	(3.39)	(1.24)
Constant	8.580***	8.359***	8.106***	9.953***	9.781***	5.661***
	(18.63)	(7.06)	(8.34)	(9.15)	(8.09)	(4.01)
Observations	77,116	12,587	23,005	16,123	14,822	10,579
Number of hh	13,573	4,371	7,294	6,154	5,197	3,234
R-squared (%)	15.03	10.22	12.72	10.13	10.78	10.47

t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

TABLE 5: Regression results - Electricity expenditures

Electricity expenditures are in general decreasing with increasing gas prices as both fuels compete for the same share of income that is allocated to energy an increase in prices probably leads to reduction of the amounts consumed of both goods[15]. The effect is again strongest for households on incomes between £30,000 and £45,000.[16] Gas is mainly used for heating and households will not likely cut back their consumption significantly if gas prices increases. Rather, it appears that

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[15] As we analyse electricity spending rather than electricity consumption we can only hypothesize about possible quantity adjustments. A price increase affects the budget constraint and households might simply reduce the consumed quantities of electricity and gas at the same time. Baker et al. (1898) find a large (negative) own price elasticity for electricity consumption. The cross price elasticity (gas) is positive. If the electricity price increases while gas price remains unchanged, households would switch to gas and consume less electricity. The own price elasticity of gas consumption is smaller (negative) and the cross price elasticity is negative, as well, indicating some complementarity of gas and electricity consumption.

[16] Controlling for both prices in this regression shows the real effect of both prices. As the increase in electricity price is driven by the gas price, the correlated leads to partly insignificant gas price coefficients. If we only control for the electricity price instead the estimated coefficients show the net effect of the two prices, i.e. the sum of the gas and electricity price coefficients:

	ALL	≤ 9,000	9T-20T	20T - 30T	30T-45T	≥ 45T
ELECTRICITY PRICE	0.71919***	0.53624***	0.68356***	0.70907***	0.77161***	0.74201***

they reduce their electricity consumption, instead which is mainly used for electric appliances.

The dummy variable NO GAS takes a value of one for households with no access to gas. We have hypothesised that these households pay more for electricity either due to lack of competition from gas or use of more electricity for heating. The estimated coefficients of the NO GAS variable support this assumption. Coefficients are relatively high but do not differ substantially between income groups.[17]

The TREND variable gives a simple linear trend for the duration of the sample. The coefficients are in general positive although they are negative for incomes of up to £20,000. The trend variable is intended to reflect unobserved measures such as home insulation activities or efficiency improvement that we cannot control for in this sample. The results indicate that for these subgroups energy efficiency of appliances has improved over time. For higher income levels efficiency improvements are likely to be over compensated by a higher number of appliances.

The variable for the ownership of homes OWNED is positively linked to electricity spending. As we do not control for durables it is possible that owners tend to live in their homes longer and use more electricity appliances and, therefore, have higher electricity expenditures. We use the number of children as an indicator of household size. As household size is correlated with income, controlling for household size leads to less meaningful results for the different income groups even though the R-squared values of the model increase. The number of children has positive significant impacts on electricity spending and many own electric appliances such as computers etc. The next group of coefficients compares how electricity spending differs for households living in different type of homes. As expected, electricity spending is highest for households living in detached houses and is lowest for those living in flats.[18]

Moving on, the results for the gas spending model are shown in Tables 6 and 7. Income elasticity of gas spending is similar to that of electricity. The spending elasticity is lowest for lower income groups and then increases in tact with income. With higher incomes the size of dwellings (independent from building types) increases and more gas is used for heating. From even higher income levels a further increase in gas consumption and heat levels is not required and the additional income is used for other purposes. Thus, the income elasticities decline. Again the inflection point can be observed at incomes between £30,000 and £45,000.

The gas price elasticity is positive and lowest for households with incomes between £30,000 and £45,000. Hence households on lower incomes are less price sensitive likely reflecting that households maintain a certain level of warmth in their homes even when prices increase. The effect of electricity price is mainly positive but is only partly significant.[19] The RURAL dummy has negative

[17] We dropped the RURAL variable in this regression because of correlation with the NO GAS dummy – coefficients for RURAL were not significant. Households with no access to gas are mainly in rural areas.

[18] Meier and Rehdanz (2008) estimate the impact of building types on household's heating expenditures per room. They find that households living in flats have the lowest heating expenditures per room and the expenditures are highest if a household lives in a detached house.

[19] In a separate estimation we only controlled for the gas price and dropped the electricity price. The gas price coefficient then captures the net effect of both prices. Results are as follows:

coefficients. Households in rural areas spend less on gas than others. They may choose less comfort or use wood and fuel oil for heating. Note that all households in the estimated model in Table 6 have access to gas. The coefficients of the two included trend variables TREND and TREND SQUARED describe an inverted u-shape relationship of gas spending over time. This likely reflects that the efficiency of heating can have improved over time and a comfortable level of heating can be achieved by using less of gas.

Dep. Variable: Log of GAS EXPENDITURES

	Coefficients					
VARIABLES	ALL	≤ 9,000	9T-20T	20T - 30T	30T-45T	≥ 45T
INCOME	0.064***	0.033*	0.051**	0.096**	0.168***	0.087***
	(13.38)	(1.89)	(2.32)	(2.23)	(3.71)	(3.40)
ELECTRICITY PRICE	0.173*	-0.010	0.112	0.182	0.581**	0.039
	(1.87)	(-0.04)	(0.61)	(0.85)	(2.57)	(0.14)
GAS PRICE	0.711***	0.757***	0.665***	0.770***	0.439**	0.930***
	(7.85)	(3.19)	(3.71)	(3.68)	(2.02)	(3.64)
RURAL	-0.066***	-0.257***	-0.105*	-0.065	-0.122**	-0.021
	(-3.38)	(-2.89)	(-1.93)	(-1.09)	(-2.43)	(-0.53)
OWNED	0.081***	0.058	0.090***	-0.001	0.075**	-0.019
	(6.34)	(1.17)	(3.38)	(-0.04)	(2.02)	(-0.38)
CHILDREN	0.153***	0.213***	0.224***	0.161***	0.139***	0.115***
	(19.44)	(4.08)	(10.23)	(8.21)	(7.84)	(6.04)
DETACHED HOUSE	0.295***	0.057	0.231***	0.216***	0.298***	0.387***
	(18.57)	(1.09)	(6.36)	(5.17)	(6.71)	(8.18)
SEMI-DET. HOUSE	0.217***	0.055	0.156***	0.162***	0.252***	0.286***
	(15.82)	(1.53)	(5.40)	(4.47)	(6.14)	(6.27)
END-TERR. HOUSE	0.202***	0.126***	0.159***	0.166***	0.153***	0.223***
	(13.09)	(3.23)	(5.02)	(4.18)	(3.36)	(4.22)
TERRACED HOUSE	0.162***	0.083**	0.144***	0.088**	0.169***	0.157***
	(11.63)	(2.34)	(4.98)	(2.37)	(3.97)	(3.39)
TREND	0.037***	0.032***	0.026***	0.039***	0.051***	0.051***
	(11.42)	(3.70)	(4.01)	(5.15)	(6.45)	(5.20)
TREND SQUARED	-0.002***	-0.002***	-0.001***	-0.002***	-0.002***	-0.002***
	(-8.08)	(-3.15)	(-3.35)	(-3.66)	(-3.87)	(-3.87)
Constant	1.217*	0.914	1.502	0.697	2.521	-0.516
	(1.71)	(0.49)	(1.06)	(0.41)	(1.41)	(-0.25)
Observations	71,619	11,178	20,826	15,112	14,258	10,245
Number of hh	12,343	3,874	6,532	5,644	4,862	3,074
R-squared	10.43	5.04	6.24	6.21	6.96	6.99

t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

TABLE 6: Regression results - Gas expenditures

The estimations for the total energy expenditure model generally show similar coefficients and development over income to those obtained for gas and electricity spending models. Table 7 shows the results for the model. It is noteworthy observation is that households with no access to gas seem to spend less on their total energy than other households. As the results for electricity spending model,

	ALL	≤ 9,000	9T-20T	20T - 30T	30T-45T	≥ 45T
GAS PRICE	0.872***	0.748***	0.768***	0.939***	0.972***	0.965***

the NO GAS variable shows these households spend more on electricity but as electricity is more expensive they tend to consume less of it.

Moreover, these households might also use oil for space heating which is cheaper heating fuel than gas. The trend variables also show a similar relationship to energy spending as to gas spending and thus the development of the total energy spending over time is mainly driven by households' spending on gas.

Dep. Variable: Log of ENERGY EXPENDITURES

	Coefficients					
VARIABLES	ALL	≤ 9,000	9T - 20T	20T - 30T	30T - 45T	≥ 45T
INCOME	0.058***	0.053***	0.050***	0.061**	0.142***	0.080***
	(17.06)	(4.11)	(3.13)	(1.98)	(4.36)	(4.58)
ELECTRICITY PRICE	0.638***	0.432**	0.424***	0.772***	1.010***	0.296
	(9.33)	(2.37)	(3.07)	(5.05)	(6.13)	(1.54)
GAS PRICE	0.140**	0.226	0.278**	0.038	-0.088	0.497***
	(2.10)	(1.26)	(2.09)	(0.25)	(-0.55)	(2.73)
NO GAS	-0.179***	-0.355***	-0.220***	-0.157***	-0.029	-0.031
	(-18.94)	(-13.50)	(-11.63)	(-6.22)	(-1.04)	(-1.14)
OWNED	0.080***	0.062*	0.058***	0.060***	0.074***	0.026
	(8.90)	(1.85)	(3.06)	(2.70)	(2.95)	(0.76)
CHILDREN	0.139***	0.121***	0.167***	0.173***	0.134***	0.108***
	(23.96)	(3.18)	(10.35)	(12.24)	(10.54)	(7.95)
DETACHED HOUSE	0.257***	0.105***	0.216***	0.145***	0.249***	0.377***
	(23.41)	(2.86)	(8.48)	(5.11)	(8.14)	(11.67)
SEMI-DET. HOUSE	0.143***	0.048*	0.134***	0.058**	0.181***	0.270***
	(15.11)	(1.86)	(6.75)	(2.36)	(6.39)	(8.58)
END-TERR. HOUSE	0.122***	0.080***	0.106***	0.077***	0.101***	0.202***
	(11.35)	(2.78)	(4.84)	(2.87)	(3.22)	(5.44)
TERRACED HOUSE	0.090***	0.017	0.091***	0.012	0.093***	0.155***
	(9.35)	(0.68)	(4.50)	(0.48)	(3.16)	(4.76)
TREND	0.013***	0.012*	0.006	0.015***	0.027***	0.022***
	(5.35)	(1.83)	(1.28)	(2.74)	(4.72)	(3.17)
TREND SQUARED	-0.001***	-0.001**	-0.001**	-0.001*	-0.001**	-0.001**
	(-3.70)	(-2.31)	(-2.30)	(-1.77)	(-2.50)	(-2.30)
Constant	6.435***	5.572***	5.302***	7.368***	7.626***	3.374**
	(12.30)	(3.96)	(5.01)	(6.06)	(5.88)	(2.33)
Observations	77,116	12,587	23,005	16,123	14,822	10,579
Number of hh	13,573	4,371	7,294	6,154	5,197	3,234
R-squared	17.71	9.46	12.00	10.77	11.61	13.33

t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

TABLE 7: Regression results - Energy Expenditures

Overall, most of estimated coefficients for our models turn over at income levels between £30,000 and £45,000. In particular, the change in income elasticities is noteworthy showing how households' lifestyles and their energy consumption patterns are different at specific income brackets. The findings suggest that the response of households to income and price changes, and other determinants of energy spending, and consequently their response to policy measures based on such determinants, varies across different income groups. For example, an electricity price increase by 10% will increase electricity spending of each income group according to their electricity price elasticity.

If policy makers seek to compensate households for this increase in spending levels they could provide some income support. If we apply this for our estimation results the income increase would need to be different for different income groups. Households in the lowest income group would need more than 8% of their income while households in the highest income group would need only less than 0.5% of additional income.

7. Conclusions

In this study we explored the links between household energy (electricity, gas and total energy spending) and income. We used observations from energy spending patterns of a large and representative sample of UK households as reference in order to identify the income thresholds at which household's essential energy needs seem to be met. We also examined in some detail the effect of a set of socio-economic determinants and drivers on household energy spending.

The findings suggest significant differences among households based on their income levels in particular in their responses to income and energy price changes. We find that income elasticity is persistently highest for households with incomes between £30,000 and £45,000. This indicates that at this income level the main energy spending and usage needs are met. Households on low incomes are less sensitive to electricity price changes but are more responsive to gas price changes than higher income households.

In addition, higher gas prices lead to lower electricity expenditures, except for the highest income group. Also, households with incomes below £20,000 are less responsive to gas price increase which suggests that they try to maintain a certain level of warmth. On the contrary, change in electricity prices leads them to reduce their electricity consumption to a larger extent than higher income households. Moreover, we find that households with no access to gas tend to pay more for electricity and might therefore have to settle for less comfort resulting in lower total energy spending.

Although the direction of impacts from the main determinants on total energy spending is similar for all income groups, the magnitude of these impacts differ considerably. Thus, policies that do not distinguish between income groups will affect these differently and can produce mixed results.

Finally, our findings show that it is not only the lowest income groups of households that may be of particular interest and policies should take into account the differing effect on the whole range of households. For example, certain policy measures such as those targeting fuel poverty, energy efficiency and saving, or taxation may need to consider a differentiated and targeted approach towards different income groups.

This study and its results lead to several new questions that would be interesting to be analyzed. Among possible directions for further research are to track energy spending of specific types of households along other dimensions such as retired, single parent mothers, or those on different types of benefits. Also, it would be useful to analyse the impacts of energy and income on less tangible aspects of welfare such as well-being.

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